Core Optics Support
Design Requirements Review

C S

Friday, March 4, 1997

@ 8:30 AM Pacific, 11:30 AM Eastern

Caltech Science Conference Room/MIT Library

Chair: David Shoemaker

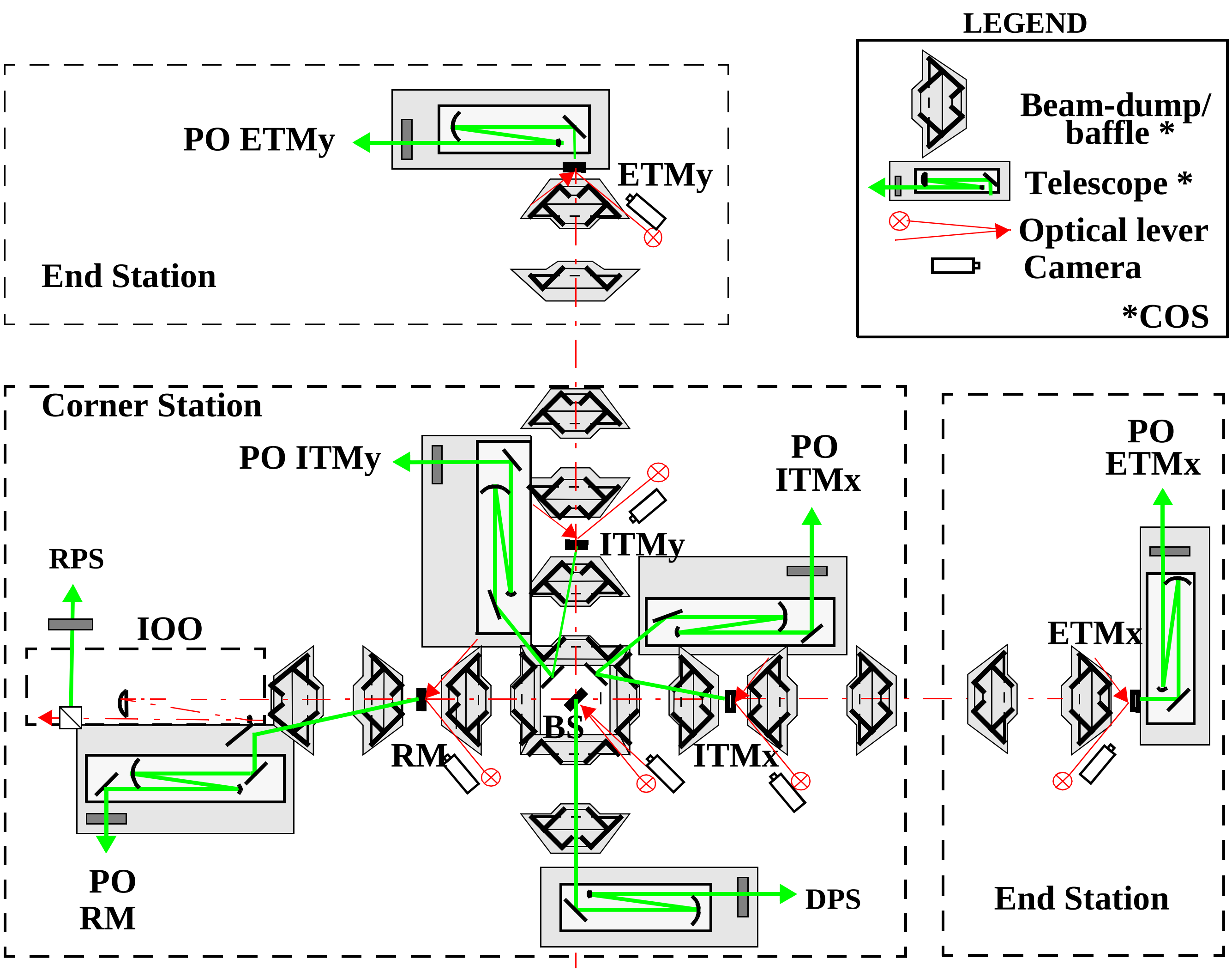
Presented by:

Michael Smith

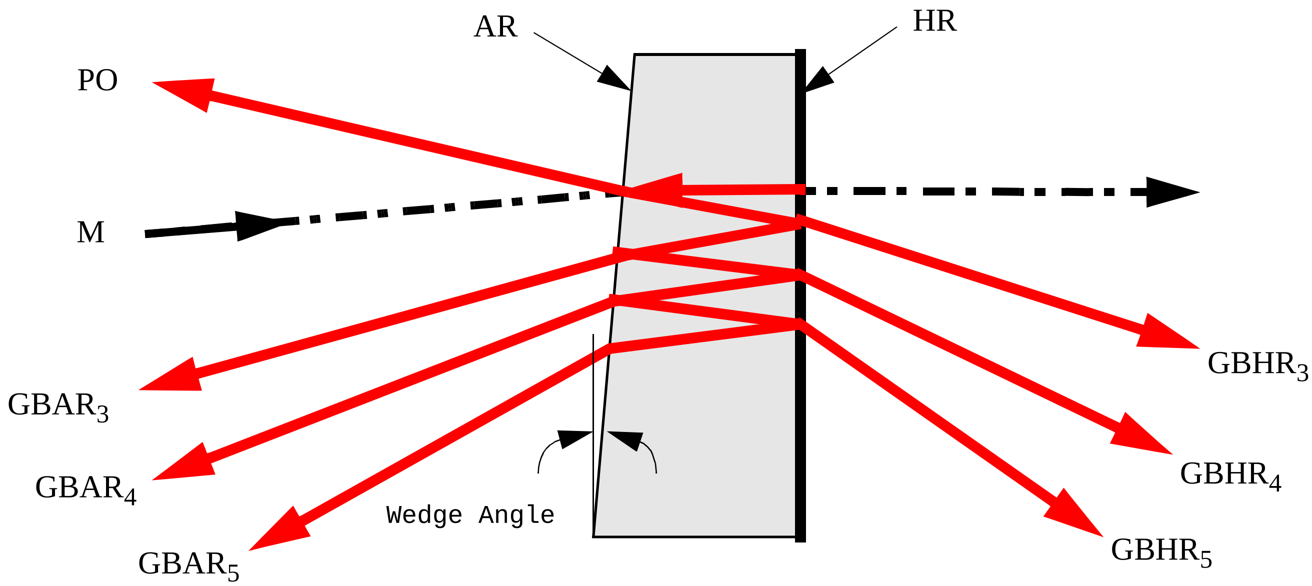
Core Optics Support
Product Perspective

- Pick-off Beams for ASC/LSC
  - ››ITM_x and ITM_y PO
  - ››ETM_x and ETM_y PO
  - ››RM PO
  - ›› DPS Output
  - ››RPS Output (belongs to IOO)
- Beam-reducing Telescopes for PO Beams
- Output Vacuum Windows for PO Beams
- Beam-dumps for Specular Ghost Beams
- Stray Light Baffles Around COC

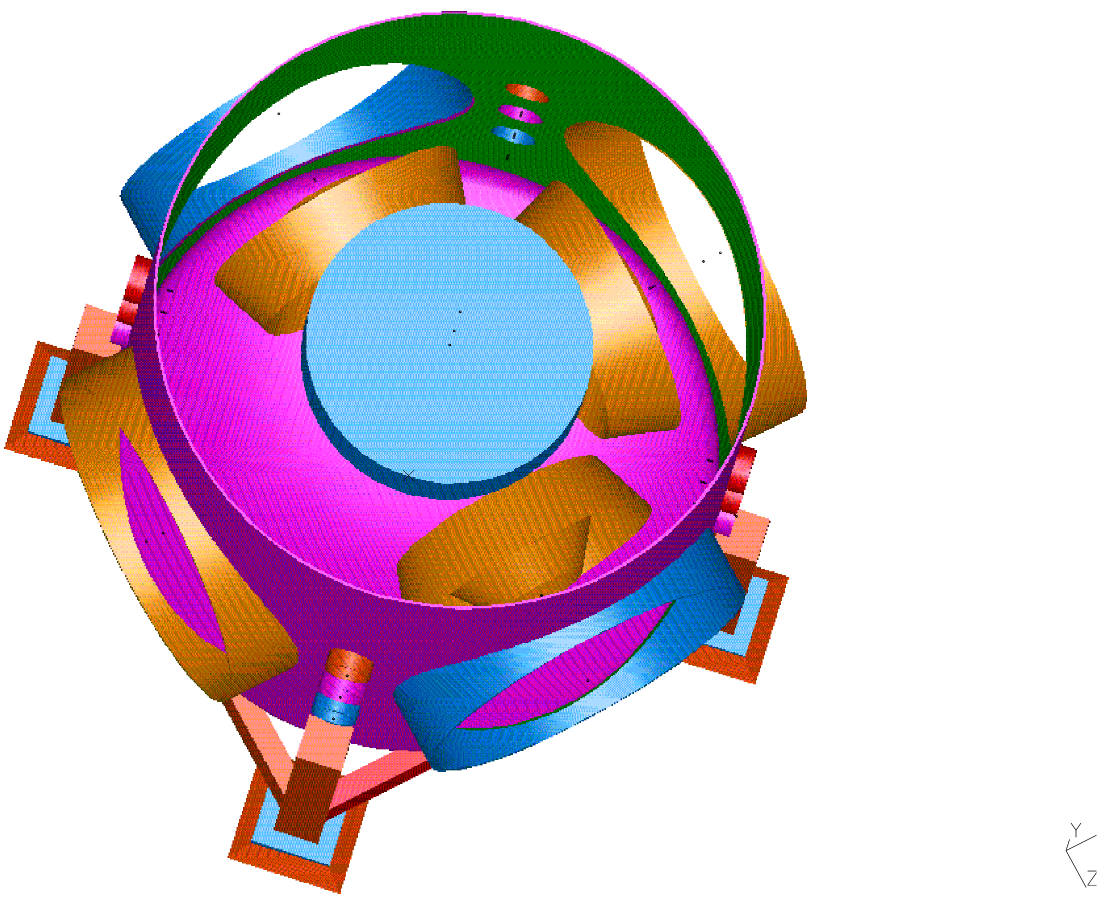
Schematic Layout of COS



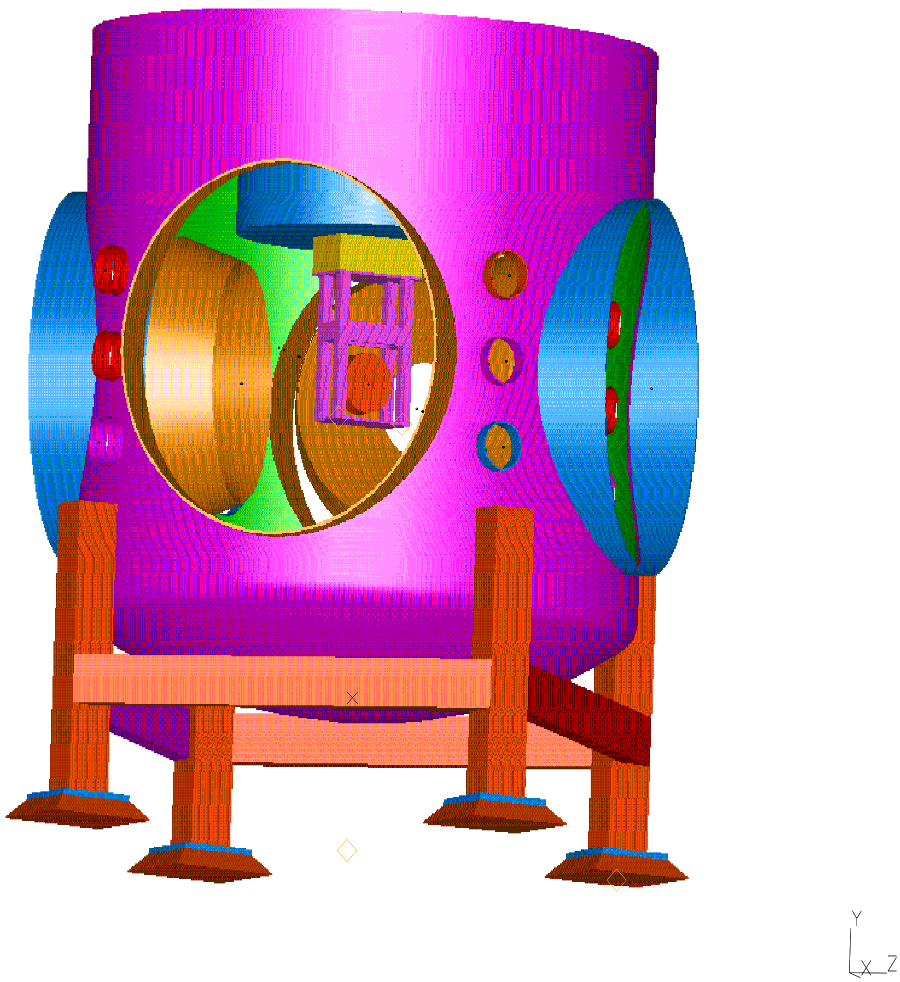
Pick-off Beams and Ghost Beams



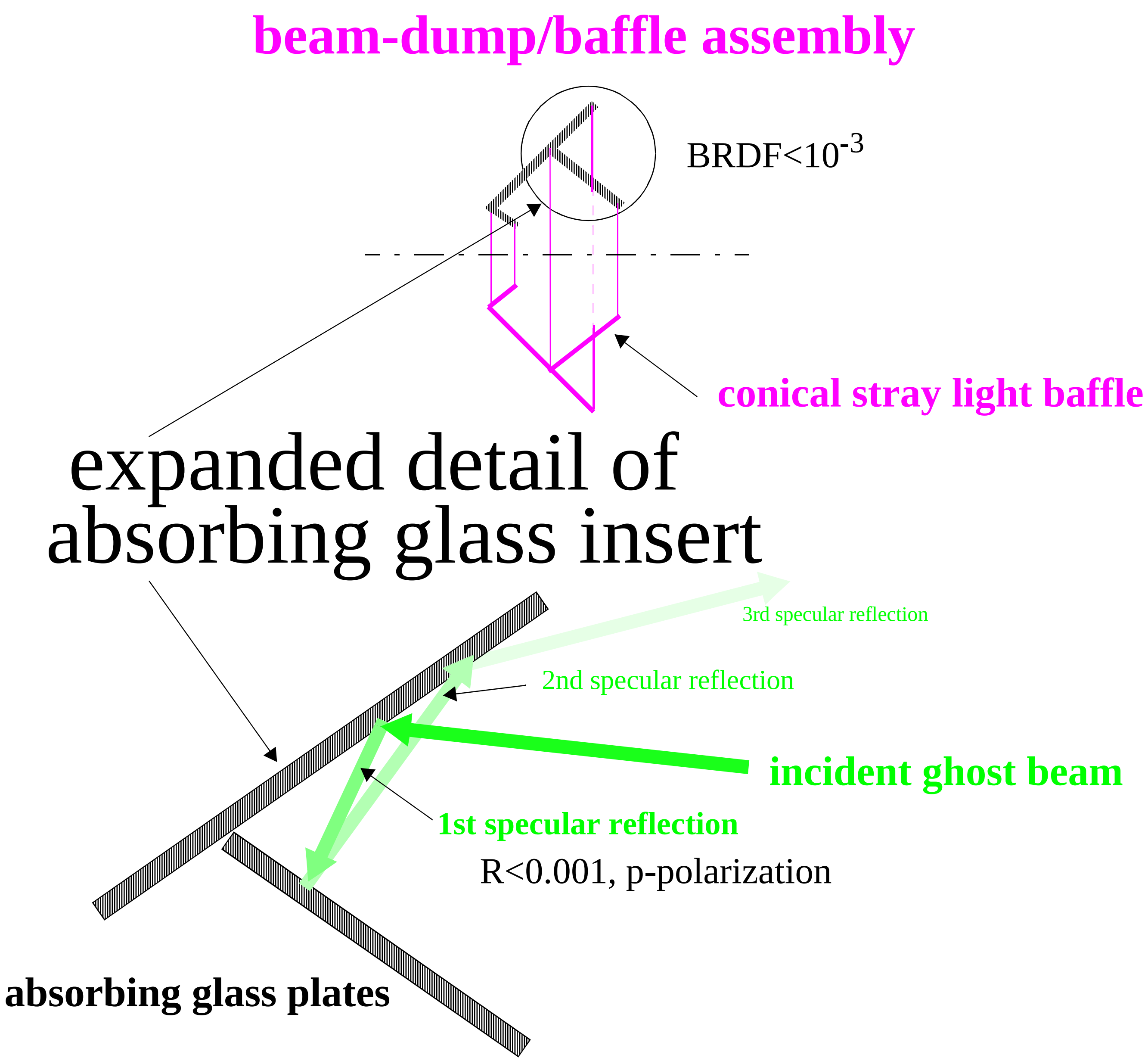
BSC Chamber with Baffles
Top View



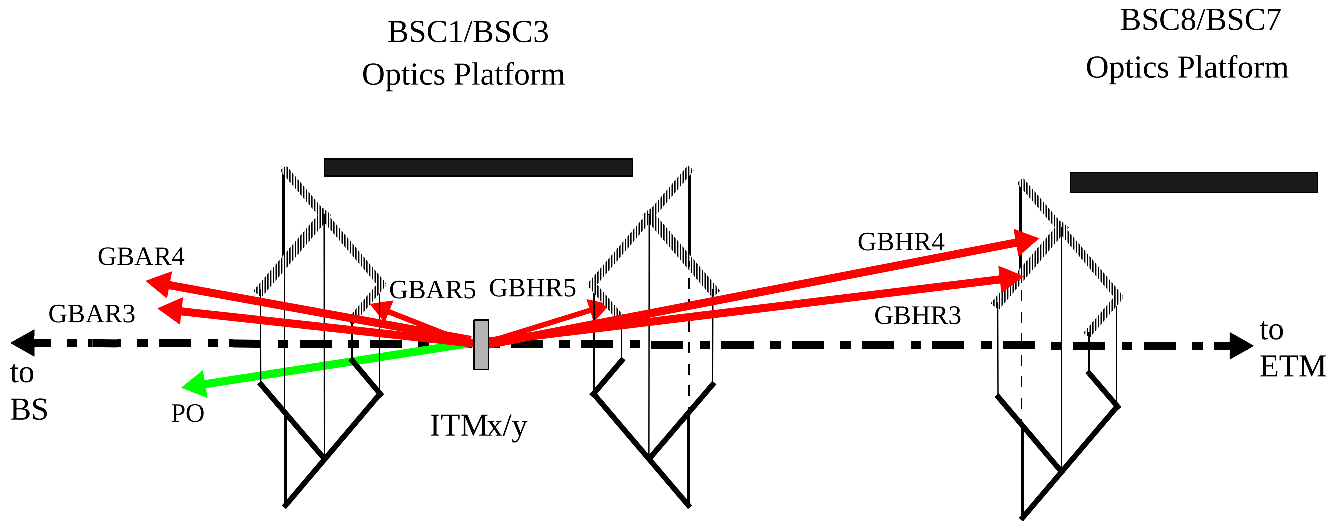
BSC Chamber with Baffles
Side View



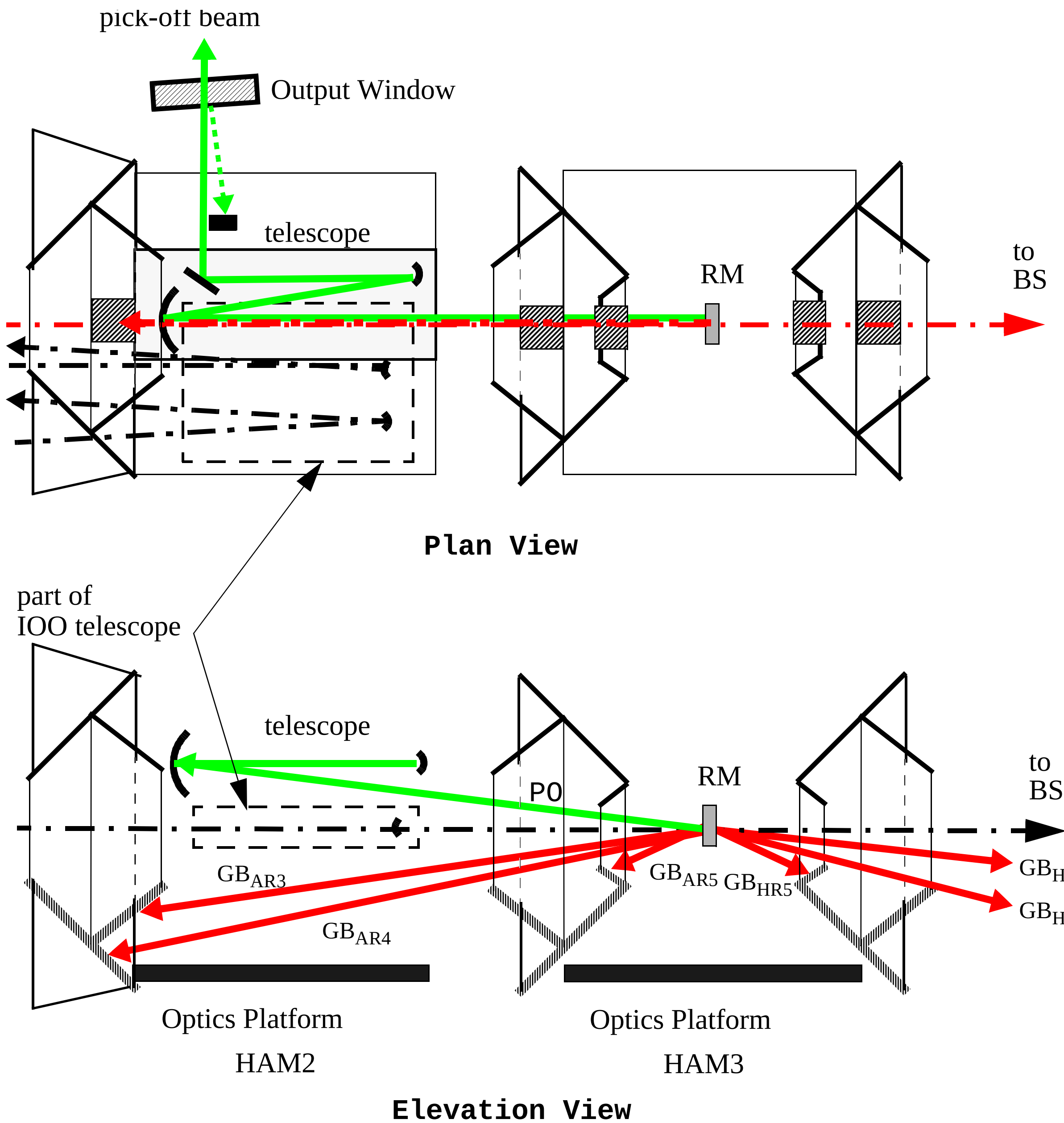
Beam-dump Black Glass Detail



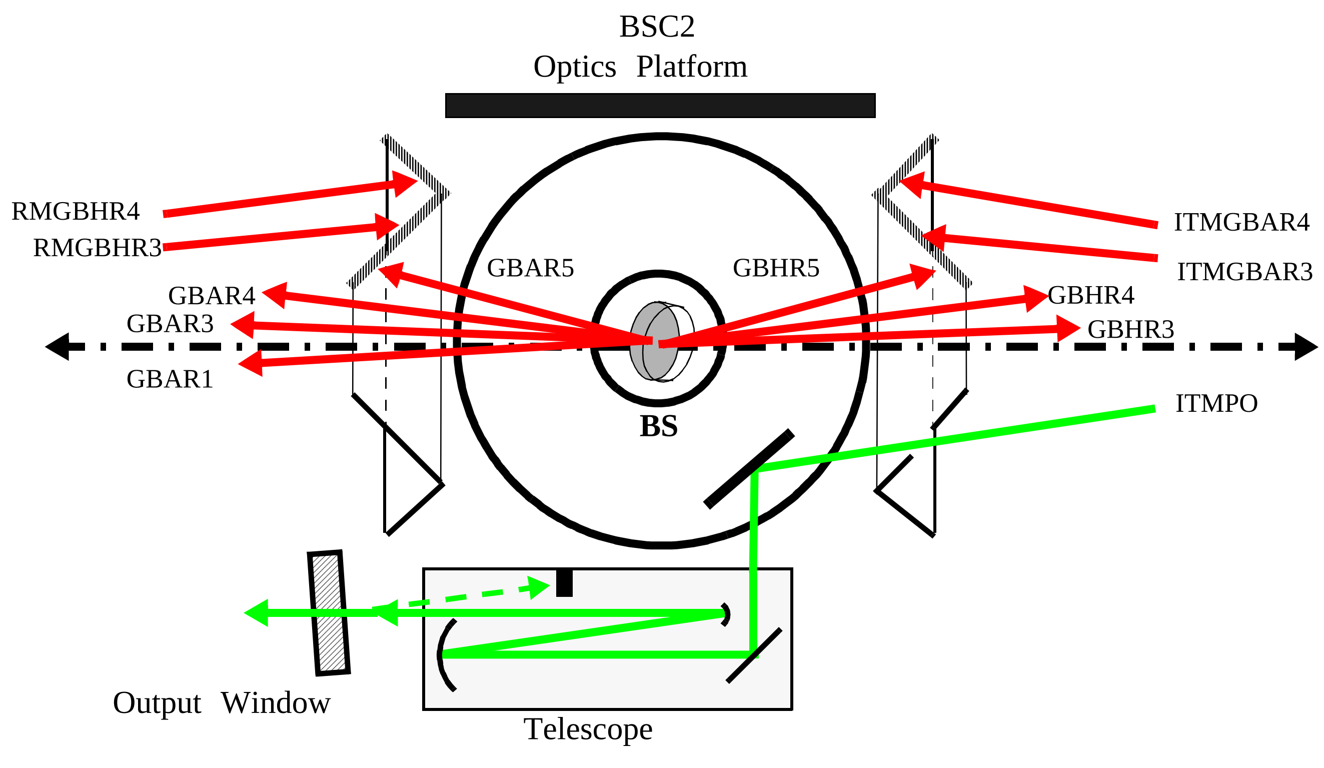
Beam-dump/baffle Concept ITM



RM Beam-dump/baffle Concept

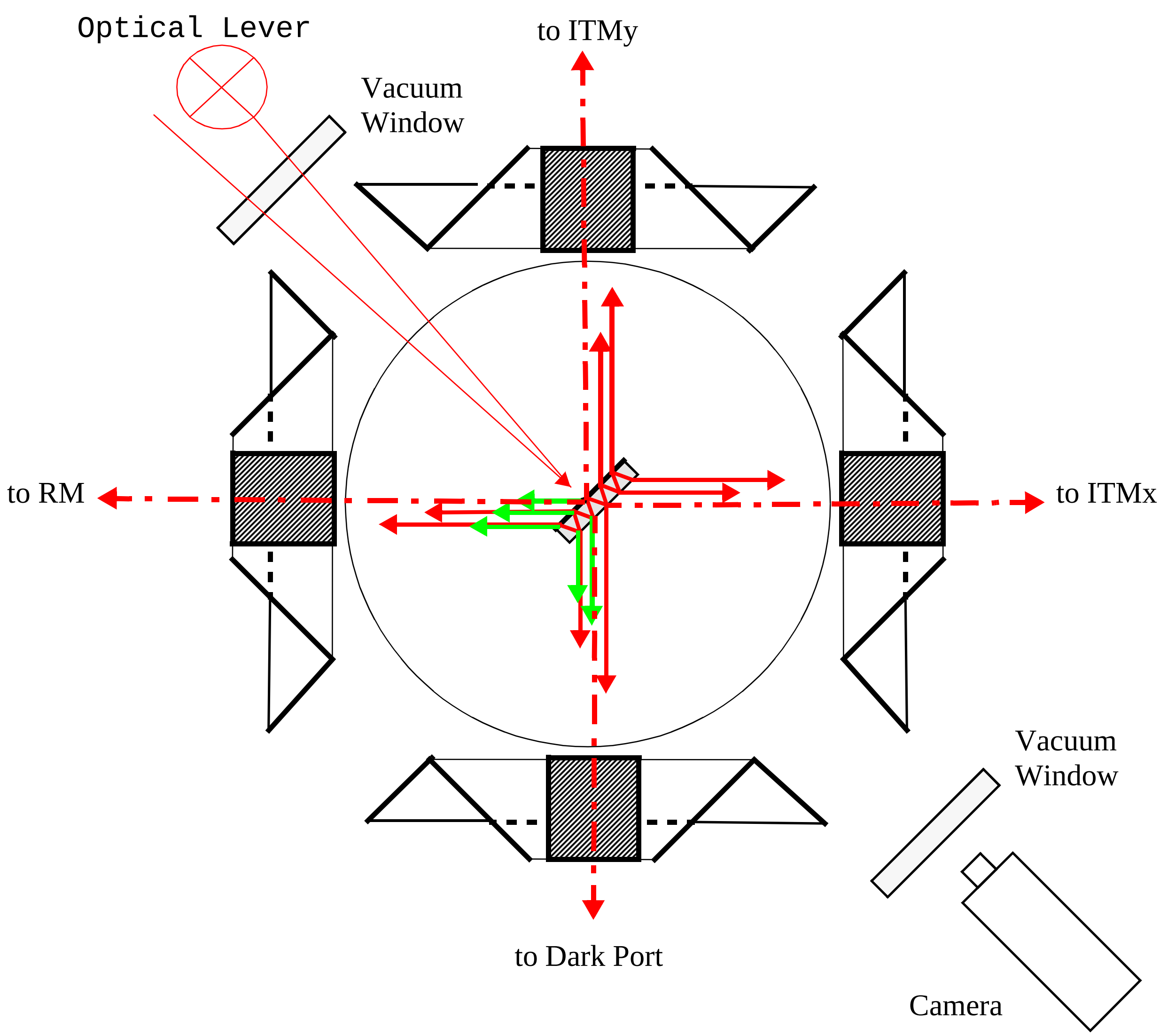


4K BS Beam-dump/baffle elevation view



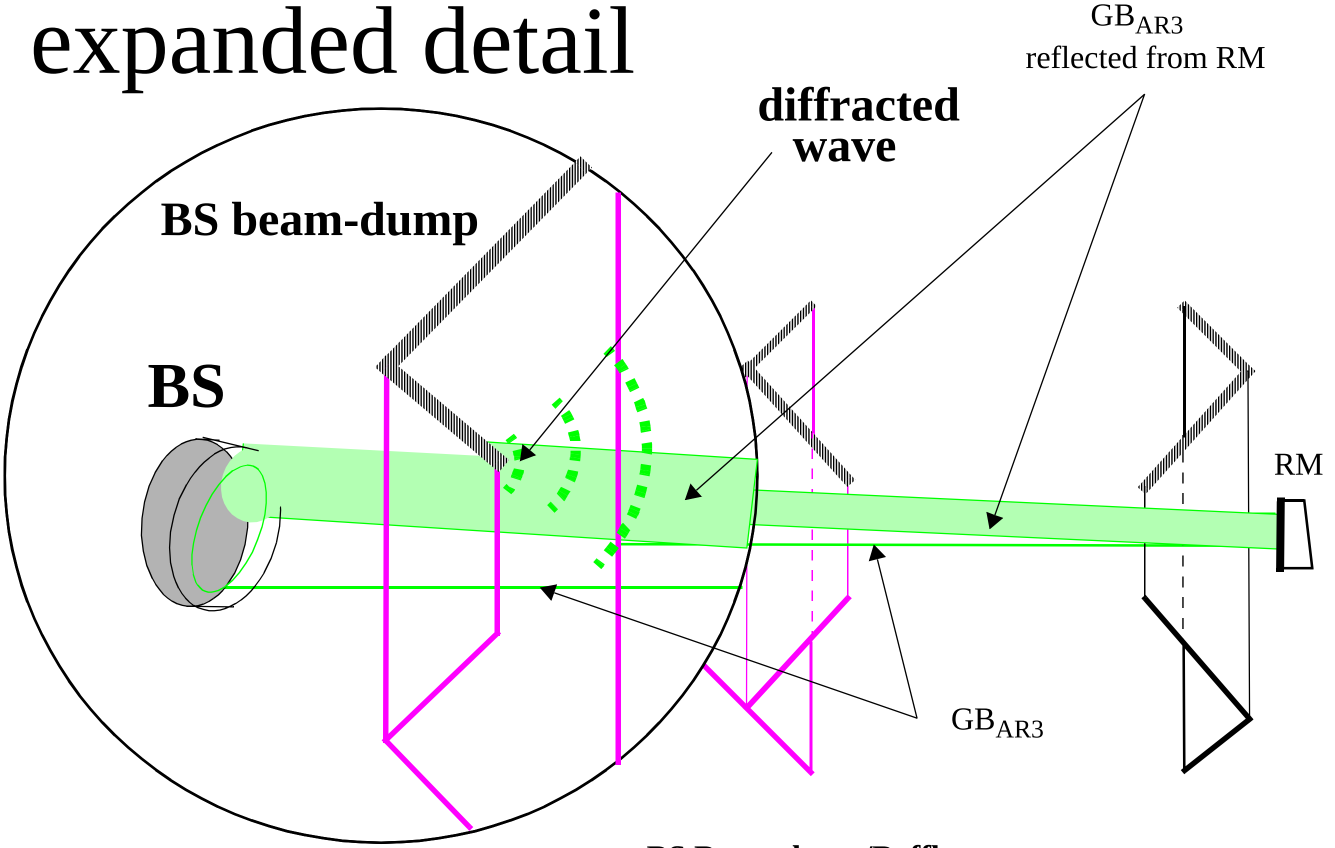
Elevation View

4K BS Beam-dump/baffle plan view



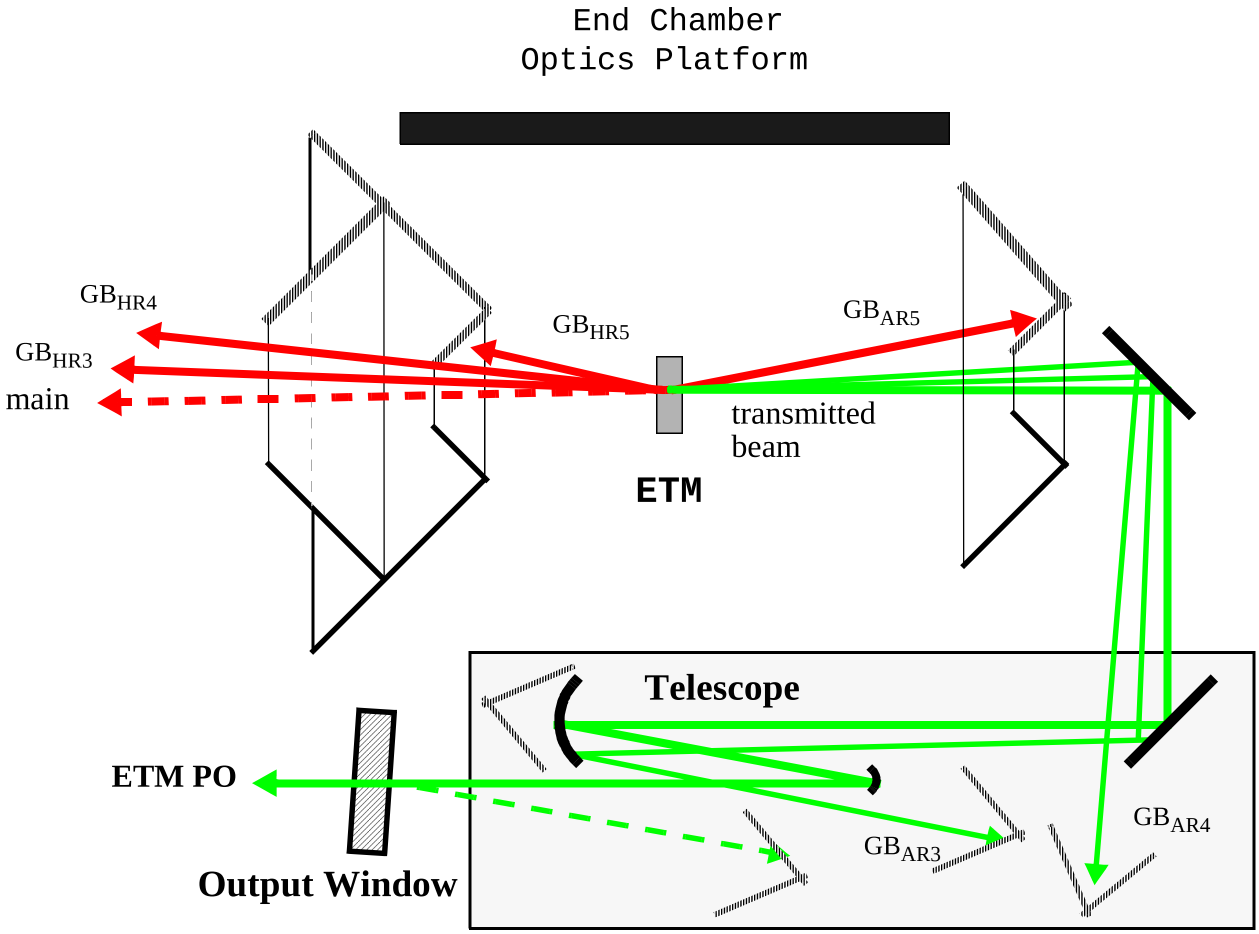
2K BS Beam-dump/baffle Edge Diffraction Effects

expanded detail

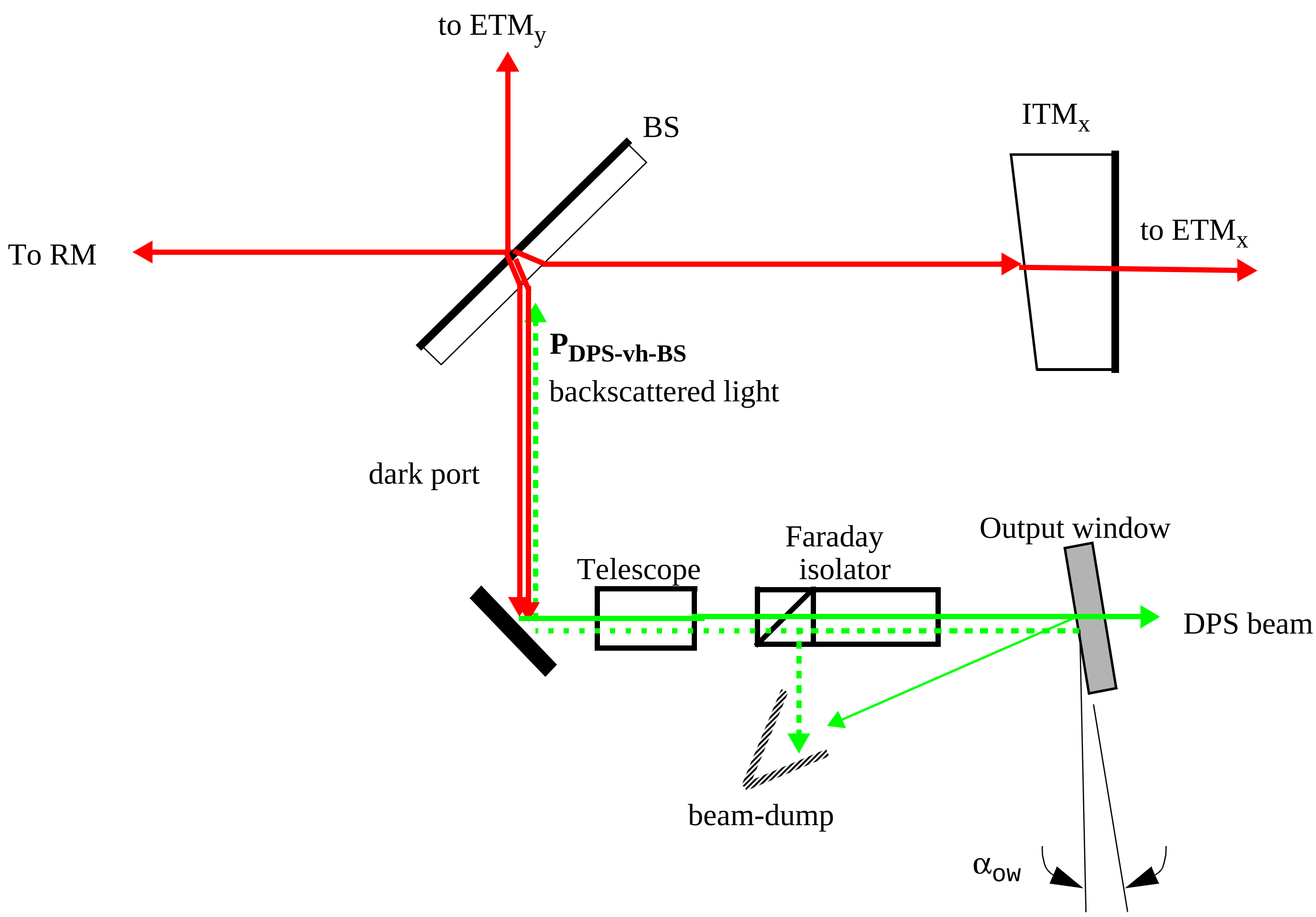


BS Beam-dump/Baffle

ETM Beam-dump/baffle Elevation View



Backscattered Power from DPS Beam



$$P_{sDPS} = 2.0\times10^{-13} watts, \ BRDF \le 8\times10^{-4} sr^{-1}$$

DPS Scattered Light Noise/Signal Ratio

- DPS Scattered Light Phase Noise Current

$$i_{sDPS} \propto \sqrt{RP_{sDPS}} \cdot \frac{4\pi x_{vh}(f)}{\lambda}$$

P_{sDPS}, light backscattered through the dark port into the IFO; R, reflectivity of FP;

$x_{vh}(f)$, horizontal displacement of scattering surface

- Gravity Wave Signal Current

$$i_g \propto \sqrt{P_{BS}} \cdot \frac{8\pi X(f)}{T\lambda\sqrt{1+\left(\frac{f}{f_0}\right)^2}}$$

P_{BS}, carrier power on BS: $P_{BS} = G_{rc} \cdot P_0$

X(f), gravity wave mirror displacement

G_{rc}, gain of recycling cavity; P_0, laser power incident on the RM; T, transmissivity of ITM

- Scattered Light Noise/Signal Ratio

$$\frac{i_{sDPS}}{i_g} = \frac{T\sqrt{R\left(1+\left(\frac{f}{f_0}\right)^2\right)}}{2} \cdot \frac{x(f)}{X(f))} \cdot \frac{1}{\sqrt{G_{rc}}}\sqrt{\frac{P_{sDPS}}{P_0}} = K_{DPS}\sqrt{\frac{P_{sDPS}}{P_0}}$$

$$K_{DPS} = 3\times10^5; @\ X_{SRD}(100Hz) = 1\times10^{-19}\frac{m}{\sqrt{Hz}},\ x_{vh}(100Hz) = 1\times10^{-11}\frac{m}{\sqrt{Hz}}$$

K_i Values for Vacuum Housing and SEI Mounted Surfaces

- Generalized Scattered Light Noise/Signal Ratio

$$\frac{i_{si}}{i_g} = K_i \sqrt{\frac{P_{si}}{P_0}}$$

- K_i Values

Scattered Light Phase Noise Current Transfer Coefficient (K_i) for Scattering from Surfaces Mounted on Vacuum Housing and SEI Platform, for Initial LIGO Sensitivity

Surface Mount	*Scattering Path*	K_i @ 30Hz	K_i @ 100Hz	K_i @ 1000Hz
Vacuum housing	ITM PO to window on vac housing into recycling cavity	3×10^5	3×10^5	6×10^2
	DPS to window on vac housing into BS	3×10^5	3×10^5	6×10^2
	ETM PO to window on vac housing into arm cavity	2×10^4	2×10^4	40
	RPS from vac housing into symmetric recycling cavity	3×10^3	3×10^3	6
SEI	ITM GB and BS GB to beam-dump on SEI into recycling cavity	300	50	0.3

Allocation of Noise Budget

- Noise Contributions from Scattering Paths
  - Noise contributed by an individual source

$$\left(\frac{is_i}{i_{gSRD}}\right)^2 = K_i^{\,2} \cdot \frac{P_{si}}{P_0}$$

  - Total noise budget

$$\left(\frac{is}{i_{gSRD}}\right)^2 = N_1 \cdot K^2{}_1 \cdot \frac{P_{s1}}{P_0} + N_2 \cdot K^2{}_2 \cdot \frac{P_{s2}}{P_0} + \ldots + N_m \cdot K^2{}_m \cdot \frac{P_{sm}}{P_0} \le \left(\frac{1}{10}\right)^2$$

- Noise Allocation Factor

$$F_i = \frac{N_i \cdot (K_i)^2 \cdot P_{si}/P_0}{\sum N_i \cdot (K_i)^2 \cdot P_{si}/P_0}.$$

- Scattered Light Requirement per Source

$$\left(\frac{P_{si}}{P_0}\right)_{REQ} \le \frac{F_i}{N_i \cdot K_i^2} \cdot \left(\frac{1}{10}\right)^2$$

LIGO

Calculation of Backscattered PO and GB Power into IFO

- Backscattered Light Power

$$P_s = P_i \cdot T \cdot [\cos\theta_{iwo} \cdot BRDF_{wo}(\theta_s)] \cdot \Delta\Omega \cdot \frac{1}{M^2} \cdot A_i$$

P_i, incident power on scattering surface

T, transmission factor through COC into IFO

BRDF, bidirectional reflection distribution function

$\Delta\Omega$, solid angle of IFO beam

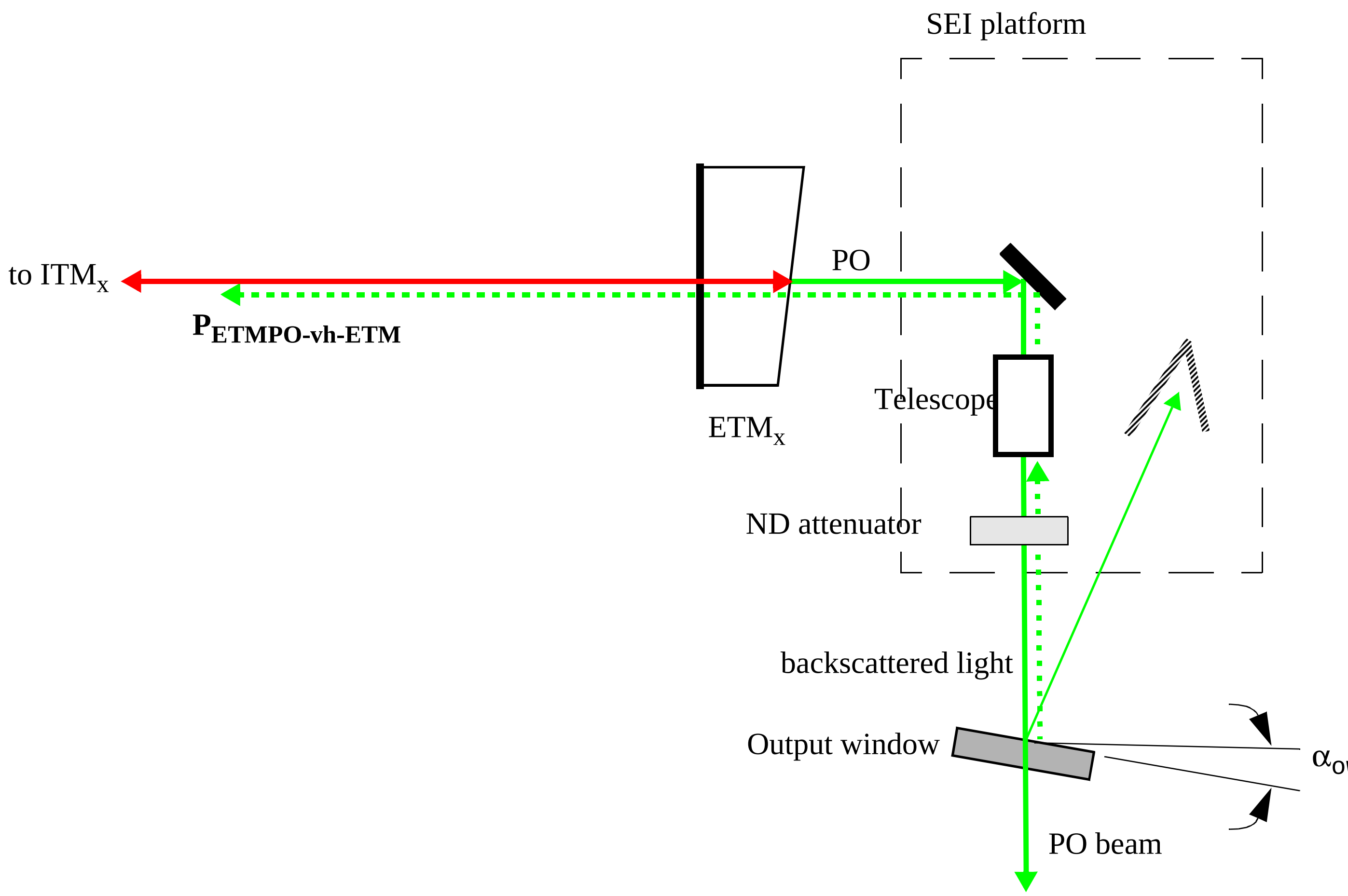
M, demagnification of incident beam

A_i, additional attenuation of scattered beam

- Implied BRDF of Scattering Surface

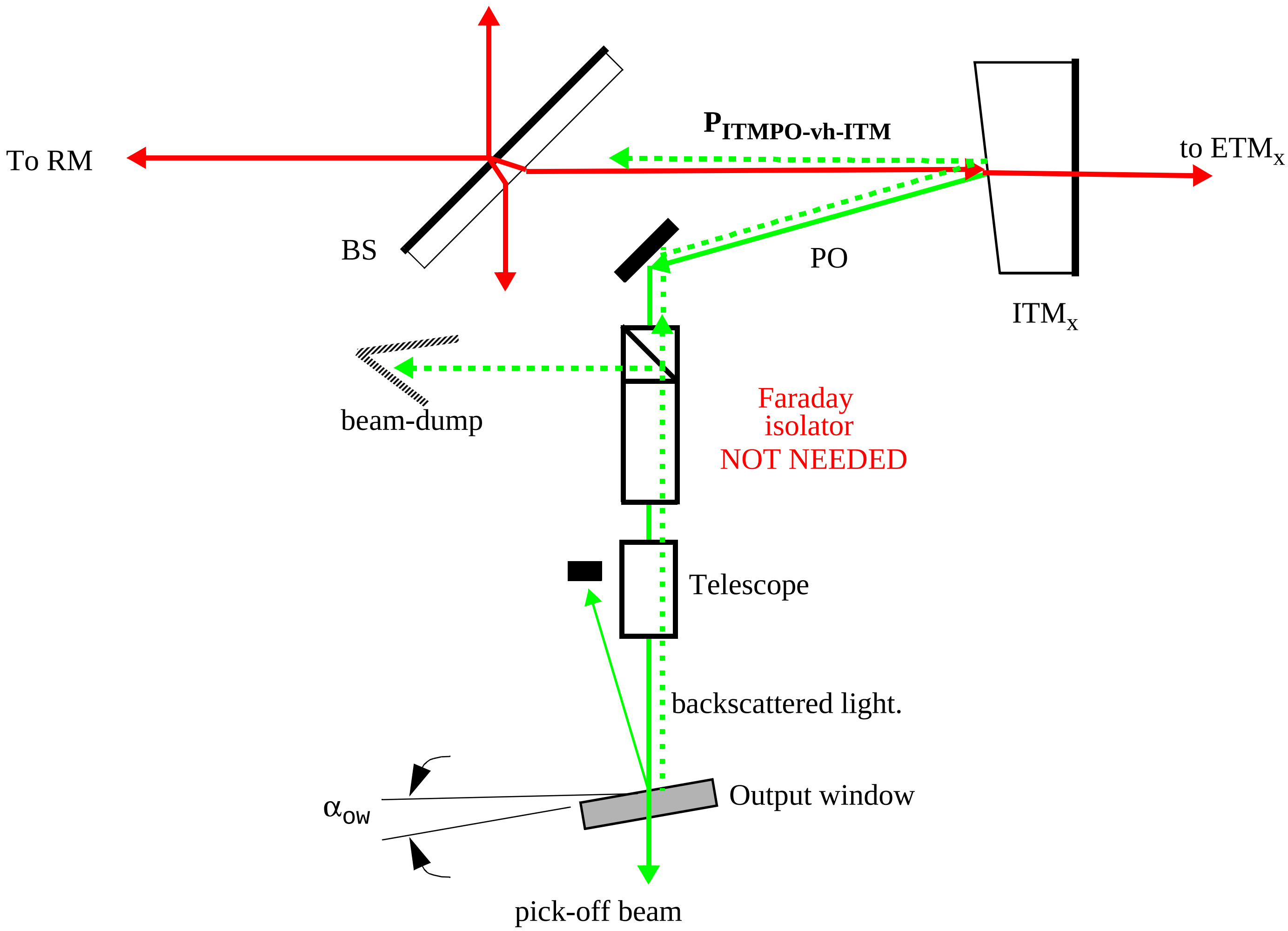
$$BRDF_i(\theta_s) = \left(\frac{P_i}{(P_s)_{REQ}} \cdot T \cdot [\cos\theta_i] \cdot \Delta\Omega \cdot \frac{1}{M^2} \cdot A_i\right)^{-1}$$

Backscattered Power from ETM PO Beam



$$P_{sETMPO} = 1.2\times10^{-11} watts,\ BRDF \leq 8\times10^{-4} sr^{-1}$$

Backscattered Power from ITM PO Beam



$$P_{sITMPO} = 1.8 \times 10^{-13} watts, \quad BRDF \le 8 \times 10^{-4} sr^{-1}$$

Summary of Scattered Light Requirements

- Vacuum Housing Mounted Surfaces

4K IFO Scattered Light Requirements @ 100 Hz, P_{laser}=6w, G_{rc}=50, M=1/72.

Scattering path	*Number of beams*	*Power incident on surface, P_i, watt*	*Noise allocation factor*	*Scattered light requirement, $(P_s)_{REQ}$, watt*	*Attenuation of scattered light path*	*Implied BRDF of all surfaces in demagnified output beam, sr^{-1}*
$I_{DPS\text{-}vh\text{-}BS}$	1	0.30	0.30	$<2.0\times10^{-13}$	$A_{FI} = 0.001$	$8\times10^{-4} sr^{-1}$
$I_{ITMPO\text{-}vh\text{-}ITM}$	2	0.15	0.27	$<1.8\times10^{-13}$	$R_{ITM} = 1\times10^{-3}$	$8\times10^{-4} sr^{-1}$
$I_{ETMPO\text{-}vh\text{-}ETM}$	2	0.39	0.08	$<1.2\times10^{-11}$	$T^2_{ND} = 0.04$	$8\times10^{-4} sr^{-1}$

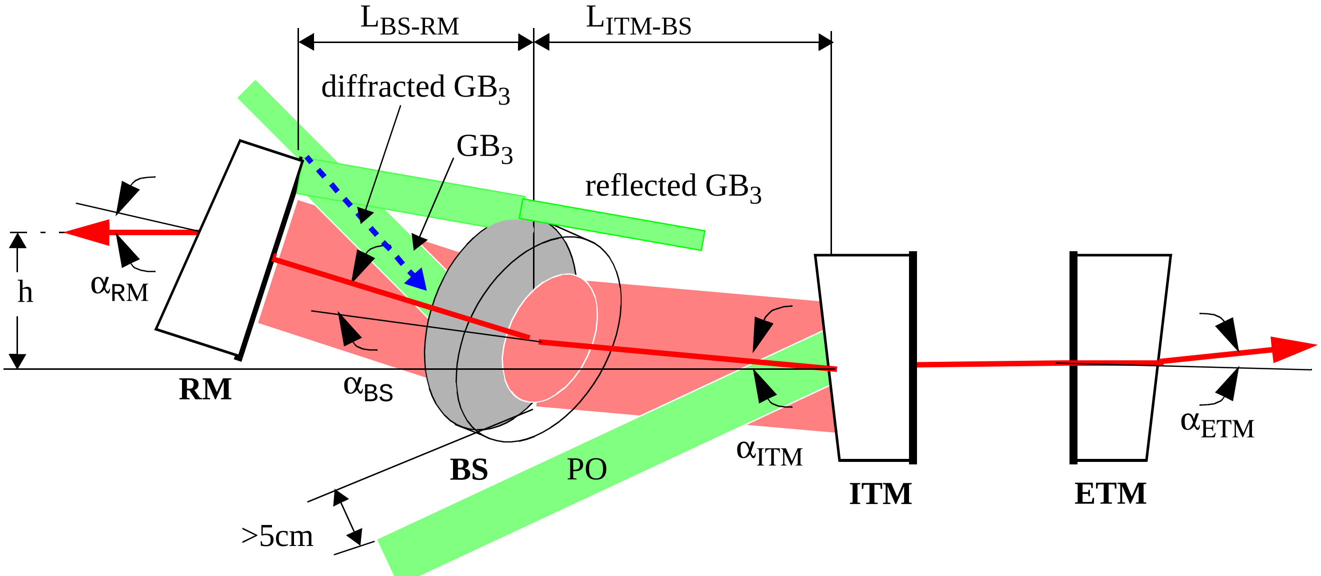
- SEI Mounted Surfaces

  ››backscattering from SEI mounted surfaces is 10^{-10} times smaller than the requirement for scattering from vacuum housing mounted surfaces and can be ignored.

- SUS Mounted Surfaces

  ››scattering from the surfaces of the COC can be ignored in comparison with scattering of PO beams from output windows.

Separation Margin of PO Beam from Main Beam

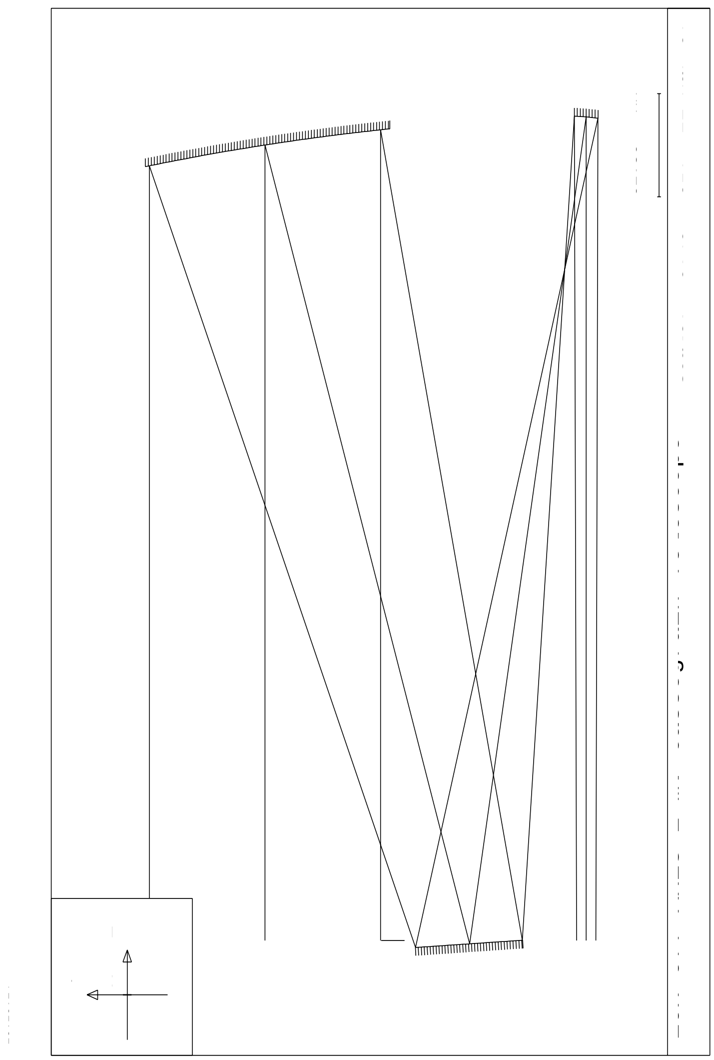


Core Optics Wedge Angle Characteristics

4K IFO Core Optics Wedge Angle Characteristics

Component	*Wedge Angle*	*axis deviation angle*	*COC height above ITM-ETM axis*	*Distance to pick-off location*	*Separation margin of PO from main beam*
RM	$2°24' \pm 5'$	$-1.083°$	8.7 cm	2.0 m	7.1 cm
BS	$1° \pm 5'$	$0.558°$	4.4 cm	4.8 m	8.6cm
ITM	$1°10' \pm 5'$	$0.525°$	0.0 cm	4.8 m	10.9 cm
ETM	$2° \pm 5'$	$0.899°$	0.0 cm	2.0 m	2.9 cm

PO Beam-reducing Telescope Optical Layout



Requirements for Beam-reducing Telescopes

Property	*Value*		*Comment*
	RM, ITM, DPS	*ETM*	
configuration	off-axis parabolic	off-axis spherical	
total curvature and astigmatism aberration[a]	$<\lambda/4$ peak-valley @ λ=1.06 micron	$<5\lambda$ peak-valley @ λ=1.06 micron	*RM, ITM, DPS*: TEM_{00}-TEM_{01} Guoy phase uncertainty <10 deg
total higher order aberrations[b]	$<\lambda/20$ peak-valley @ λ=1.06 micron	$<1\lambda$ peak-valley @ λ=1.06 micron	*RM, ITM, DPS*: TEM_{00}-TEM_{01} Guoy phase uncertainty <10 deg
input clear aperture diameter	156 mm	156 mm	RM, ITM, DPS:@100 ppm beam power diameter, <1% loss in WFS signal; ETM:@ 3000ppm diameter
output clear aperture diameter	15.6 mm	15.6 mm	compatible with ASC input requirements
Internal resonance and Q	TBD	TBD	
output beam parameter	3.64 mm	3.64 mm	
output beam waist location	TBD	TBD	compatible with ASC input requirements
magnification	0.1X	0.1X	compatible with ASC input requirements

a. based on a private communication from Daniel Sigg regarding an estimate of the ASC signal loss with a $\lambda/4$ peak-valley wavefront aberration @ λ=1.06 micron

b. same as above

Requirement for PO Beam Output Window

- Wavefront Distortion

Optical path length distortion with two surfaces $OPD = 2 \cdot (1 - n) \cdot \Delta t$

Wavefront distortion with surface figure $\Delta t = \frac{\lambda}{20}$, $OPD = 0.045\lambda$

- Summary of Requirements

Requirements for PO Beam Vacuum Window

Property	*Value*
material	fused silica
thickness	TBD
substrate diameter	TBD
wedge	$34° \pm 5'$
clear aperture	>20 mm
surface figure	λ/20 per surface over clear aperture
AR coating, both surfaces	<.001 @1064 nm, @ 55.4° incidence angle, p-polarization
$BRDF_{wo}$	< 5x 10^{-2} sr^{-1}
Vacuum properties	Vacuum Equipment Specification, LIGO-E940002-02-V

COS TBD Issues

- Testing and Fixtures
  - ››BRDF measurement apparatus for COS surfaces
  - ››Test equipment for receiving inspection
  - ››Telescope alignment fixtures
  - ››IFO Ghost and PO beam location sensor, for initial alignment
- Beam-reducing Telescope
  - ››position of output beam waist, magnification ratio, cost trade-off
- Output Window
  - ››substrate diameter and thickness
- Resonant Frequencies and Damping of COS Elements Mounted on SEI Platforms
- BRDF of ASC/LSC Optical Surfaces

Mock-up of BSC and HAM Stations

Needed for the Determination of:

- Configuration of Beam-dump/baffles
- Telescope configuration, size, and mounting constraints
- Mounting Configurations and Interfaces with other Subsystems on SEI Platform
- Stay-Clear Zones for PO Beams
- Access for Optical Levers, and COC TV Cameras
- Installation and alignment procedures
- Maintenance access